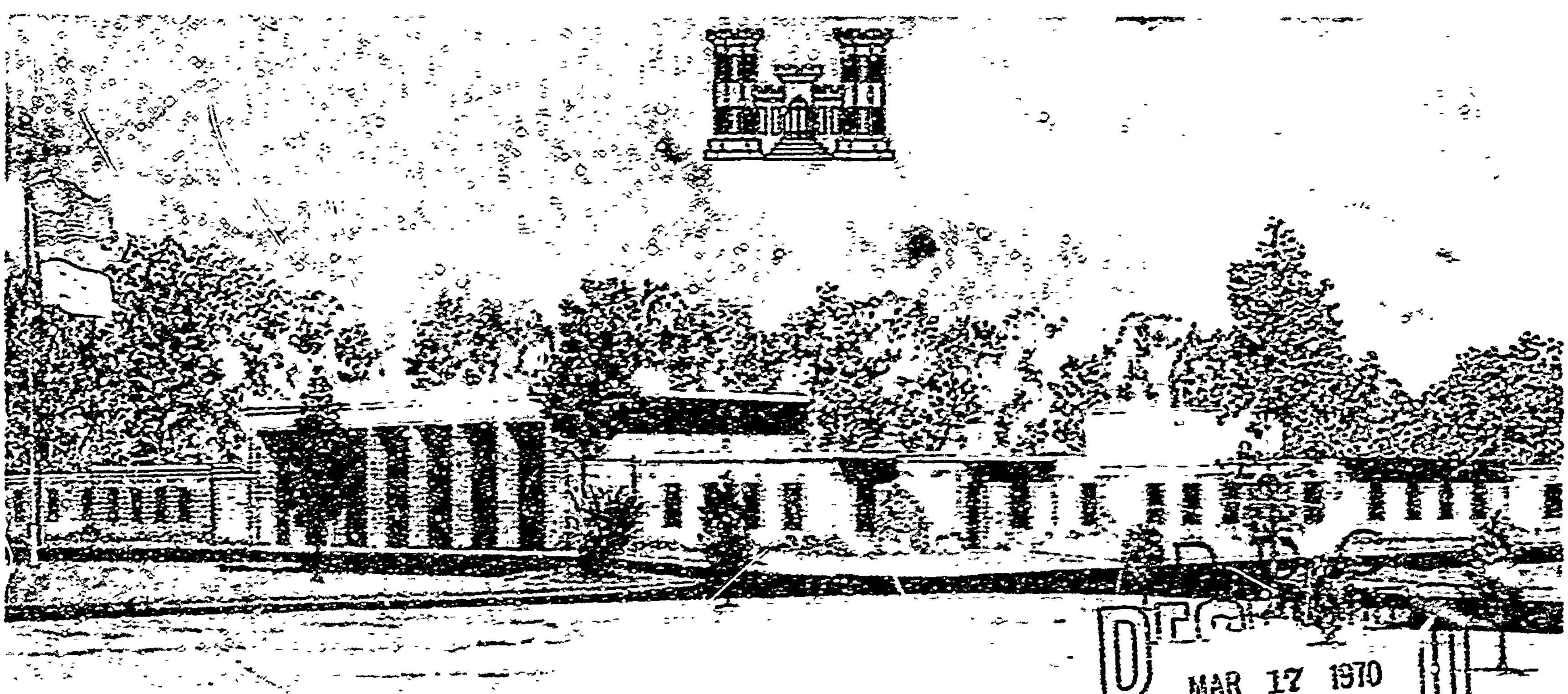
TECHNICAL REPORT NO. 3-783

AN ANALYTICAL MODEL FOR PREDICTING CROSS-COUNTRY VEHICLE PERFORMANCE

APPENDIX D: PERFORMANCE OF AMPHIBIOUS VEHICLES IN THE WATER-LAND INTERFACE (HYDROLOGIC GEOMETRY)

by

C. A. Blackmon, B. G. Stinson, J. K. Stoll



February 1970

Sponsored by Advanced Research Projects Agency

and

Directorate of Development and Engineering, U. S. Army Materiel Command

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Conducted by U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi 39180

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ARMY-MRC VICKSBURG, MISS

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FOREWORD

The study reported herein was performed by the U. S. Army Engineer Waterways Experiment Station (WES) for the Office, Secretary of Defense (OSD), Advanced Research Projects Agency (ARPA), and is a portion of one task of the overall Mobility Environmental Research Study (MERS) sponsored by OSD/ARPA for which the WES was the prime contractor and the U. S. Army Materiel Command (AMC) was the service agent. The broad mission of Project MERS was to determine the effects of the various features of the physical environment on the performance of cross-country ground contact vehicles and to provide therefrom data that can be used to improve both the design and employment of such vehicles. A condition of the project was that the data be interpretable in terms of vehicle requirements for Southeast Asia. The funds employed for this study were allocated to WES through AMC under ARPA Order No. 400. Some funds for preparation and publication of this report were provided by the Directorate of Development and Engineering, AMC, under Department of the Army Project 1V025001A131, "Military Evaluation of Geographic Areas," and Task -02, "Surface Mobility," of Project 1T062103A046, "Trafficability and Mobility Research." The study was performed during the period April 1965 to October 1965 under the general guidance and supervision of the MERS Branch of the WES, the staff element of WES responsible for the technical management and direction of the MERS program.

This appendix is one of seven to a report entitled An Analytical Model for Predicting Cross-Country Vehicle Performance. These appendixes are:

A. Instrumentation of Test Vehicles

B. Vehicle Performance in Lateral and Longitudinal Obstacles (Vegetation)

Volume I: Lateral Obstacles

Volume II: Longitudinal Obstacles

C. Vehicle Performance in Vertical Obstacles (Surface Geometry)

D. Performance of Amphibious Vehicles in the Water-Land Interface (Hydrologic Geometry)

E. Quantification of the Screening Effects of Vegetation on Driver's Vision and Vehicle Speed

F. Soil-Vehicle Relations on Soft Clay Soils (Surface Composition)

G. Application of Analytical Model to United States and Thailand Terrains

The study was conducted by personnel of the Mobility and Environmental (M&E) Division, under the general supervision of Mr. W. J. Turnbull, Technical Assistant for Soils and Environmental Engineering; Mr. W. G. Shockley and Mr. S. J. Knight, Chief and Assistant Chief, respectively, M&E Division; Mr. A. A. Rula, Chief, Vehicle Studies Branch; Mr. W. E. Grabau, Chief, Terrain Analysis Branch; and Mr. J. K. Stoll, Chief, Obstacle-Vehicle Studies Section. Special acknowledgment is made to Mr. E. S. Rush, Chief, Soil-Vehicle Studies Section, who provided data essential to the analysis from his "work in progress." The tests reported herein were conducted by Mr. B. G. Stinson. Analysis of the data was performed by Mr. C. A. Blackmon. This report was written by Messrs. Blackmon, Stinson, and Stoll.

Directors of the WES during this study and preparation of this report were COL Alex G. Sutton, Jr., CE, COL John R. Oswalt, Jr., CE, and COL Levi A. Brown, CE. Technical Directors were Messrs. J. B. Tiffany and F. R. Brown.

CONTENTS

CONVERSION FACTORS, BRITISH TO METRIC UNITS OF MEASUREMENT

British units of measurements used in this report can be converted to metric units as follows:

Multiply	By	To Obtain
inches	2.54	centimeters
feet	0.3048	meters
miles (U. S. statute)	1.609344	kilometers
cubic inches	16.3871	cubic centimeters
gallons (U. S. liquid)	0.003785	cubic meters
pounds	0.45359237	kilograms
tons (2000 lb)	907.185	kilograms
pounds per square inch	0.070307	kilograms per square centimeter
foot-pounds	0.138255	meter-kilograms

SUMMARY

Forty tests were conducted with two amphibious tracked vehicles and one amphibious wheeled vehicle at Eglin Air Force Base, Fla., and near Khon Kaen, Thailand, to determine the vehicles' capabilities for exiting closed bodies of water. Empirical relations, based on the data collected in this study and in previous studies, are presented to support the conclusions that performance of amphibious tracked and wheeled vehicles (in terms of "go-no go") in the water-land interface can be correlated with soil strength (expressed as average cone index of the 0- to 6-in. soil layer), and that the slope-climbing ability in the water-land interface of the tracked vehicles tested compares favorably with that of the same vehicles operating on land surfaces of similar soil composition and consistency.

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AN ANALYTICAL MODEL FOR PREDICTING CROSS-COUNTRY VEHICLE PERFORMANCE

APPENDIX D: PERFORMANCE OF AMPHIBIOUS VEHICLES IN THE WATER-LAND INTERFACE (HYDROLOGIC GEOMETRY)

PART I: INTRODUCTION

Background

1. The main text of this report describes the development of an analytical model for predicting the cross-country performance of a vehicle. The model was based on an energy concept within the framework of classical mechanics that requires that cause-and-effect relations be established between discrete terrain factors and vehicle response. The terrain factors considered in the analytical model are (a) surface geometry, (b) surface composition, (c) vegetation, and (d) hydrologic geometry. This appendix deals with one aspect of the hydrologic geometry factor--the effects of the water-land interface on vehicles exiting from bodies of water. The configuration of the bank, coupled with the position of the water surface with respect to that configuration, may be more critical to cross-country movement than the presence of water per se. In addition to the adverse bank geometry, the bank surface may consist of weak or slippery materials, which further affect vehicle performance.

2. Although the importance of the problems associated with stream exits has long been recognized, at the beginning of this program few, if any, tests had been conducted for the specific purpose of investigating these problems and no definitive data were available. However, results of slope-climbing tests in wet fine- and coarse-grained soils were available and were used both in the design and analysis of the tests reported herein.

Purpose and Scope

3. This appendix describes the water-land interface tests conducted in the United States and in Thailand during the period October-April 1965.

The general purpose of these tests was to obtain data relating characteristics of the water-land interface to vehicle performance in terms suitable for use in developing that portion of the analytical model for cross-country performance. The specific purposes were (a) to determine if vehicle performance in terms of "go-no go" could be related to the slope, composition, and strength of the soil at the water-land interface, and (b) to compare vehicle performance in the water-land interface and on land areas of similar composition and consistency.

4. Forty tests were conducted with three amphibious vehicles at two general locations. The tests were conducted in closed water bodies to eliminate the influences of wave action and current velocity. Surface composition of the test sites in terms of the Unified Soil Classification System (USCS) ranged from silty sands (SP-SM) to fat clay (CH) in the 0- to 12-in.* layer. Bank slopes ranged from 11 to 68 percent.

* A table of factors for converting British units of measurement to metric units is presented on page ix.

PART II: TEST PROGRAM

Location and Description of Test Sites

5. One test site (E-H-5) was at Eglin Air Force Base (AFB) near Fort Walton Beach, Fla. (fig. D1). The site was approximately 20 miles northwest of Fort Walton Beach and about 10 miles north of the intersection of Highways 98 and 87. All other test sites were about 6 miles south of

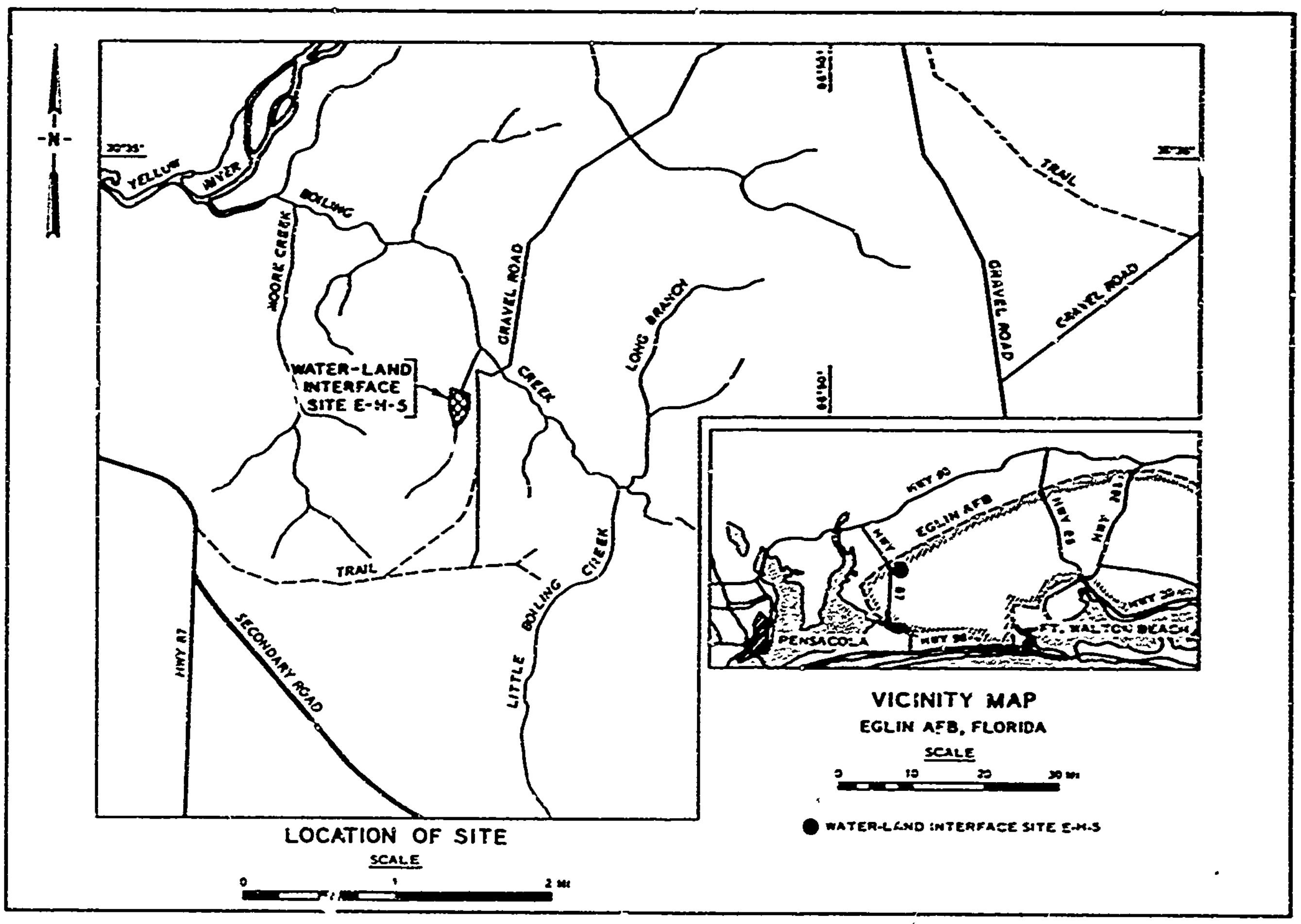


Fig. D1. Location of test site, Eglin AFB, Fla.

Khon Kaen, Thailand, in roadside borrow pits adjacent to Highway 21 (fig. D2).

Eglin AFB test site

6. The test site was a small reservoir that provided ideal conditions for testing on the slopes of the dam embankment. The slopes of the embankment where the tests were conducted ranged from 25 to 51 percent.

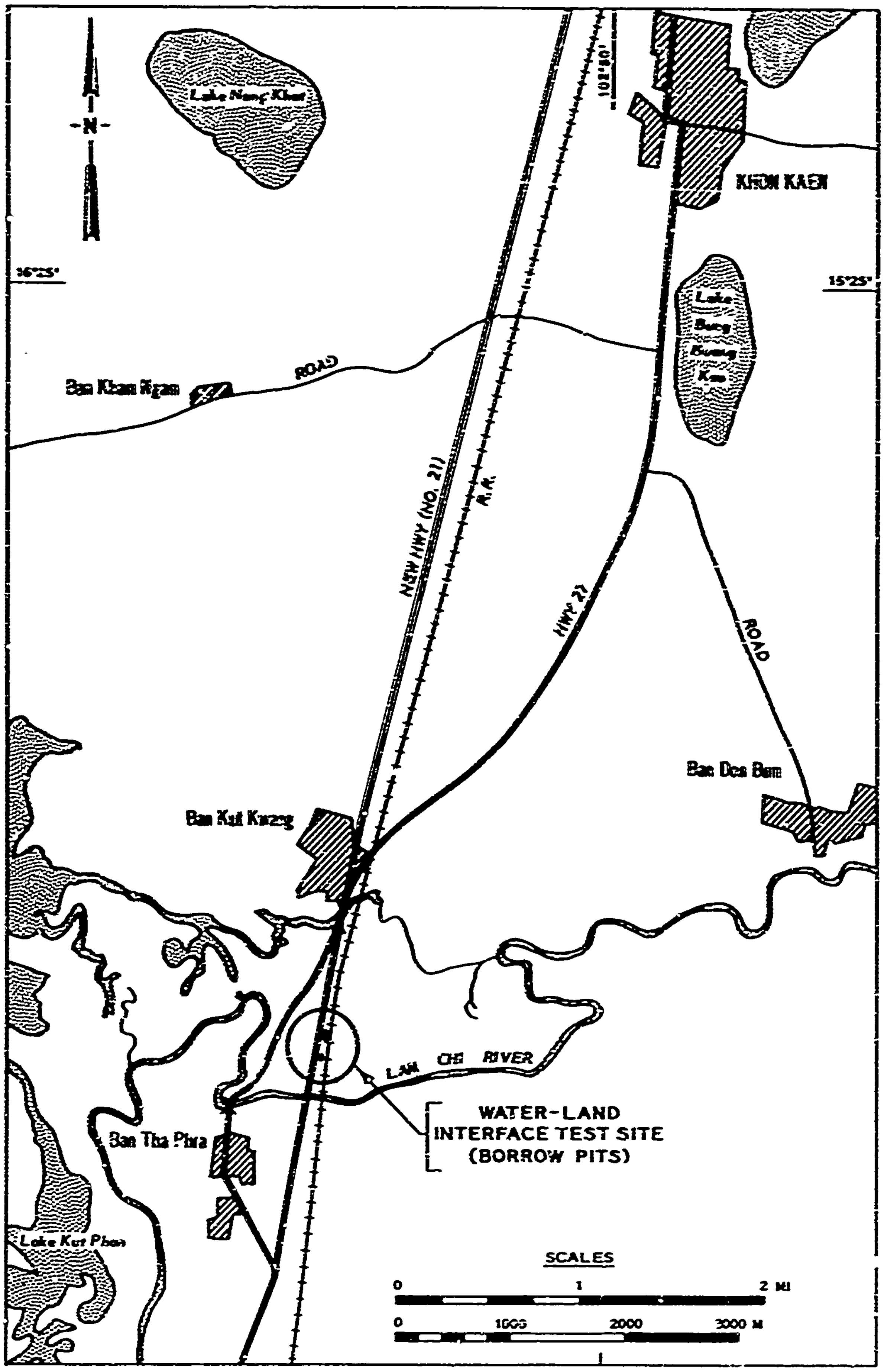


Fig. D2. Location of test site area, Khon Kaen, Thailand

The soil to depths of 12 in. consisted of silty sands (SP-SM) (see table D1). The section of embankment selected for testing was void of vegetation except for scattered clumps of water weeds and grass (fig. D3).

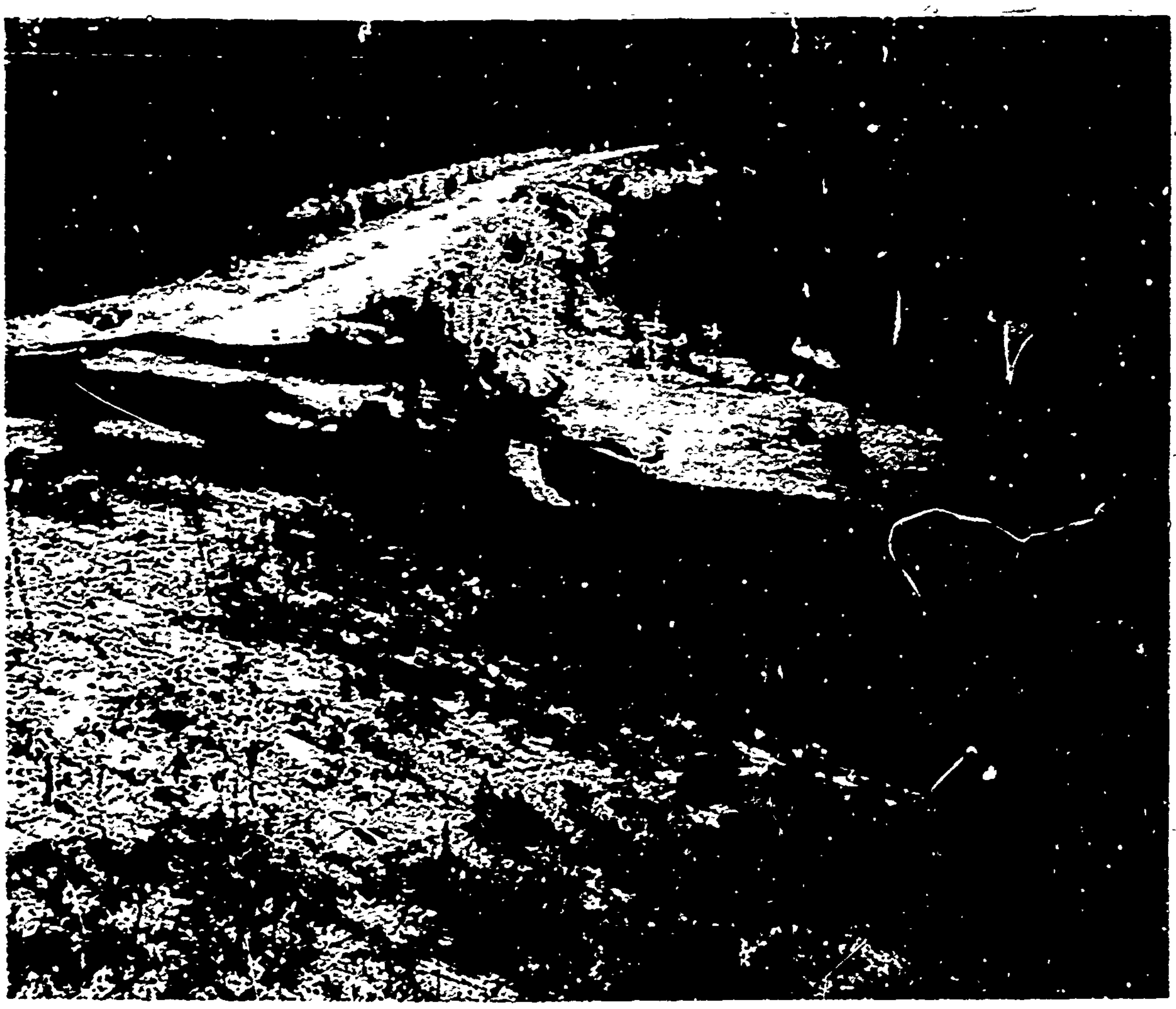


Fig. D3. Site E-H-5, Eglin AFB

Khon Kaen test sites

7. Ten sites were selected at the borrow pits south of Khon Kaen. They were designated 5-H-1 E, 5-H-1 W, 5-H-2 through 5-H-8, and 5-H-10. The maximum slope at these sites varied from 11 to 68 percent. The soils to depths of 12 in. were predominantly silts and clays. Most of the sites were void of vegetation; however, a few sites supported a sparse cover of short water grasses. A summary of soil data is given in table D1. Two of the test sites are shown in fig. D4.

a. Site 5-H-3

b. Site 5-H-7

Fig. D4. Sites 5-H-3 and 5-H-7, Khon Kaen

Vehicles Tested

8. Three amphibious vehicles were used in the testing program. Two of these vehicles were personnel carriers propelled by track-laying systems. The third vehicle was an articulated cargo truck propelled by rubber-tired wheels. The two tracked vehicles were equipped with fairly elaborate measuring and recording systems.* Descriptions of the three vehicles and pertinent engineering characteristics are presented in the following paragraphs.

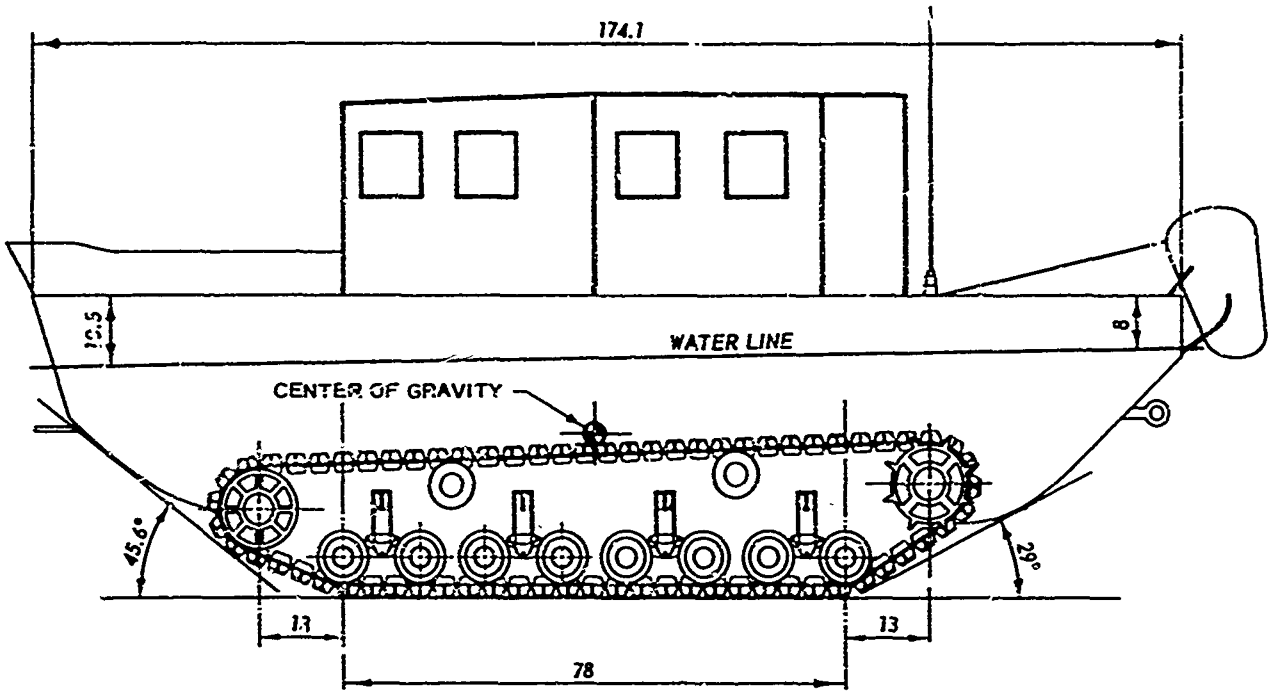
Amphibious cargo carrier, M29C

9. The M29C is a low silhouette, tracked vehicle (fig. D5) designed to transport personnel or light cargo on land and water. Watertight compartments in bow and stern add to the buoyancy of the vehicle. The stern

Fig. D5. Amphibious cargo carrier, M29C

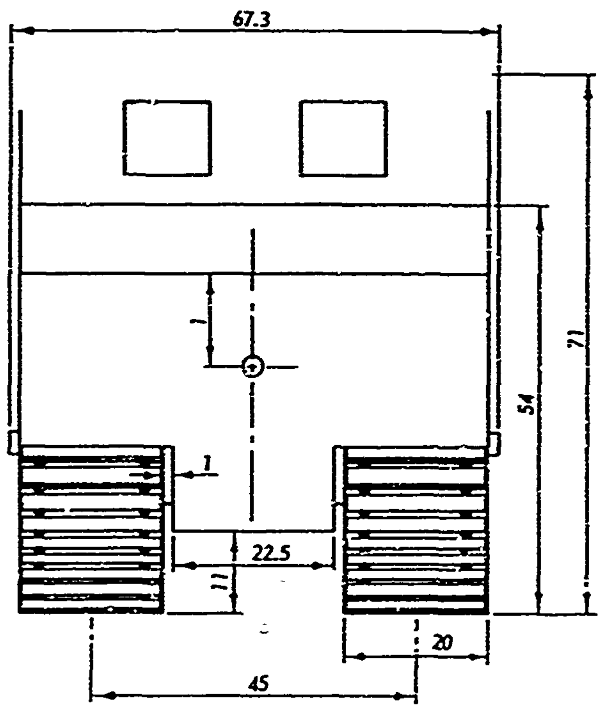
compartment is fitted with rudders to steer the vehicle in amphibious operations. The vehicle is powered with a liquid-cooled six-cylinder engine located in the right front of the hull. Power is transmitted from the engine to the rear axle by a power train consisting of a single plate clutch, conventional transmission, and a two-speed axle unit with combined

* This instrumentation is discussed in detail in Appendix A of WES Technical Report No. 3-783.[1]



A. SIDE VIEW

NOTE: ALL DIMENSIONS ARE IN INCHES.



B. FRONT VIEW

Fig. D6. Dimensions of the M29C

planetary differential. The vehicle weighs 4778 lb empty. Maximum recommended payload, including crew, is 1200 lb, making a maximum gross weight of 5978 lb and a ground contact pressure of 1.92 psi. For the tests reported herein, gross vehicle weight was 5600 lb for the Eglin AFB tests and 6100 lb for the Thailand tests (ground contact pressures of 1.79 and 1.96 psi, respectively). Physical dimensions of the vehicle and other pertinent information are given in fig. D6.

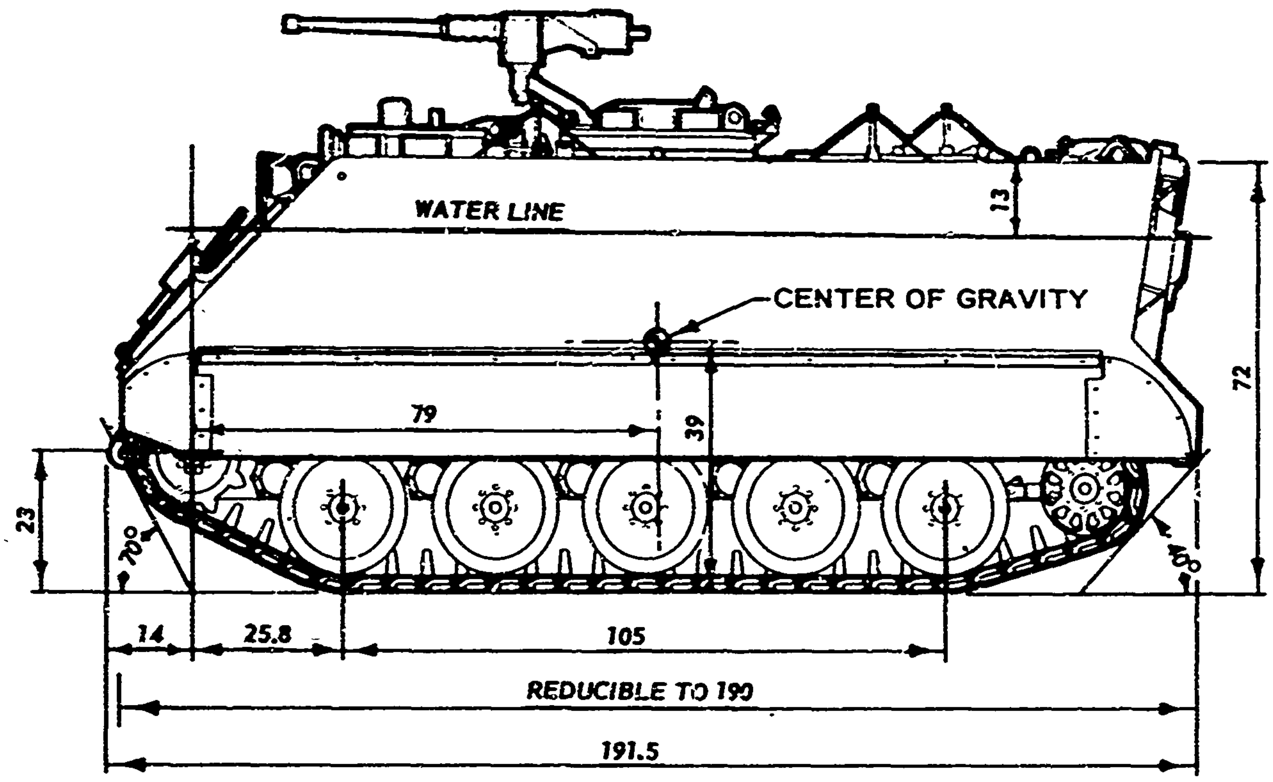
Amphibious personnel carrier, M113

10. The M113 armored personnel carrier is a tracked vehicle (fig. D7) designed to transport 12 troops, plus driver. It is capable of amphibious operation across lakes and streams, of extended cross-country travel over rough terrain, and of high-speed operation on improved roads and highways. Power is supplied by a 209-hp Chrysler Model 75 M engine coupled through a transfer case to an Allison TX200-2A transmission (hydraulic) and an FMC DS200 controlled differential. The M113 has torsion-bar suspension with 10 individually sprung, dual rubber-tired bogie wheels. Dimensions of this vehicle are shown in fig. D8. The net weight of the vehicle is 20,310 lb. Combat loaded and fully equipped the gross weight is 23,520 lb. Ground contact pressure for combat operation is 7.5 psi. During conduct of the water-land interface tests the vehicle weight was 22,018 lb, and ground contact pressure was accordingly reduced to approximately 7.0 psi. When floating, the distance from the bottom of the vehicle's tracks to the waterline is 59 in. Evaluation of results of tests of the amphibious capabilities of the M113 have been previously reported by Development and Proof Services, U. S. Proving Ground, Aberdeen, Md.[2]

Fig. D7. Armored personnel carrier M113

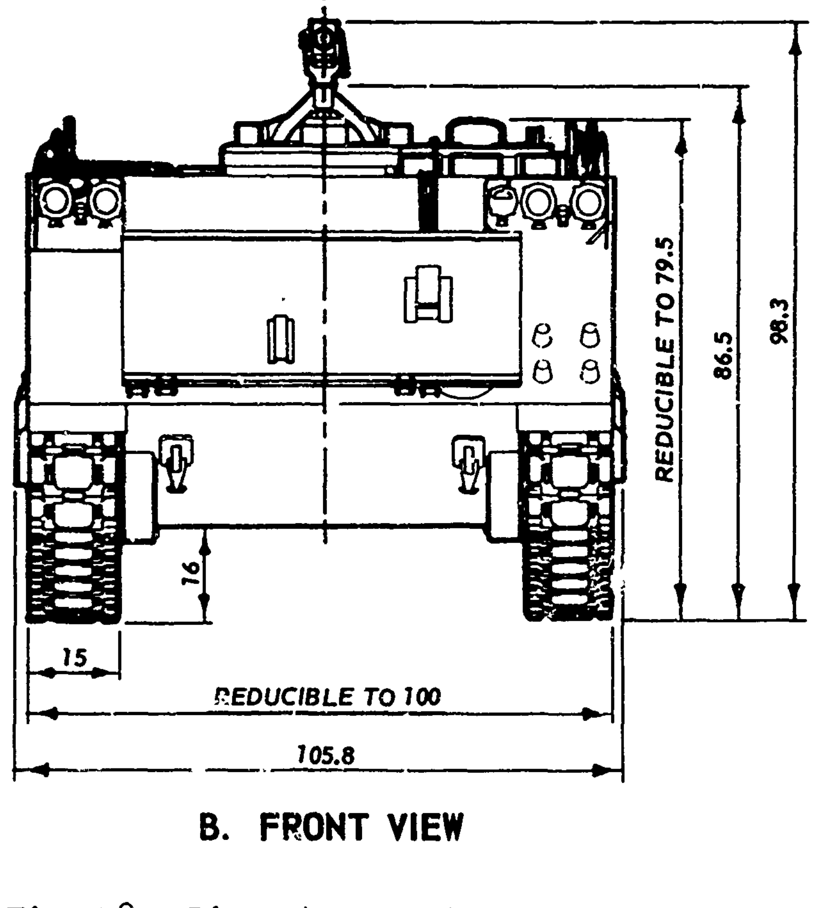
XM561, 6x6, 1-1/4-ton cargo truck

11. The XM561 is a wheeled vehicle (fig. D9) that was designed to replace current standard 1/2- and 3/4-ton vehicles. It is capable of amphibious operation across lakes and streams, of off-road operation over fairly rough terrain, and of high-speed operation on improved roads and highways. Dimensions of the XM561 are given in fig. D10. Other pertinent engineering characteristics of the XM561 are shown on page D12.



A. SIDE VIEW

NOTE: ALL DIMENSIONS ARE IN INCHES.



B. FRONT VIEW

Fig. D8. Dimensions of the M113

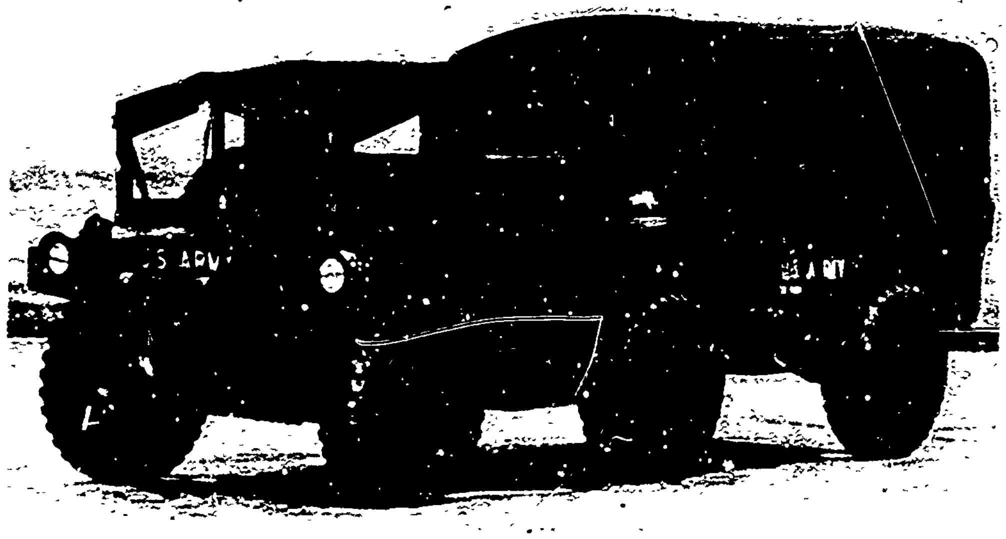


Fig. D9. XM561, 6x6, 1-1/4-ton articulated cargo truck

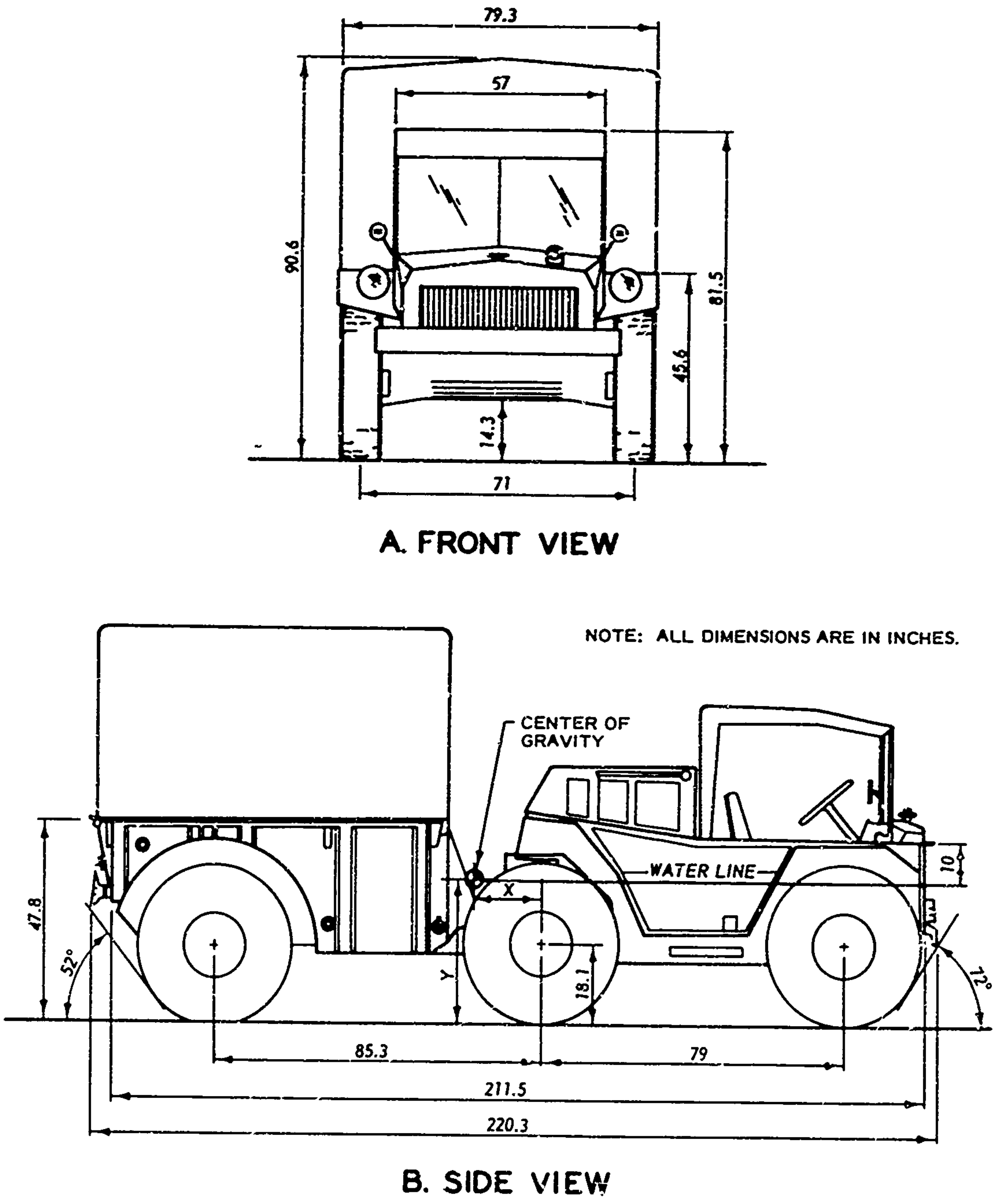


Fig. D10. Dimensions of the XM561

Weight:
  Curb--6370 lb
  Gross---9280 lb
  Tested--9480 lb

Tires: (Tubeless, NDCC, 11.00-18, 4-PR)
  Cross-country inflation pressure------------------------12 psi
  Tire diameter (at 12 psi)----------------------------37.0 in.
  Tire deflection (percent of tire section height at 1547 lb and 12 psi)------------------------18.5 percent
  Ground contact pressure for cross-country travel is approximately 12 psi.

Transfer---Manual, two speed, ratios 1.05:1 and 1.80:1

Transmission---four speeds forward, one reverse. Manual synchromesh except first and reverse. Ratios 7.06:1, 3.58:1, 1.71:1, 1.00:1, and reverse 6.78:1.

Engine---Three cylinder, liquid cooled, vertical in-line diesel, Model GM3-53, 159.3-cu-in. displacement, 103 hp at 2800 rpm, 215 lb-ft torque at 1500 rpm.

Fuel capacity--40 gal

Suspension---Independent, with coil spring at each wheel on front and rear axles. Single-leaf springs on center axle. Center axle rolls ± 15 deg left or right independent of spring deflection.

Steering---Mechanical coordinated steering of front and rear wheels.

Special features---Articulated two-body design. Roll at center axle ± 15 deg, rear axle ± 30 deg; pitch at rear axle ± 40 deg. Vehicle floats and swims using wheels for propulsion.

12. The articulated two-body design concept of the XM561 provides near uniform loading of the six wheels on nearly all types of terrain. It is this articulation feature of the vehicle that allows ± 30-deg roll and ± 40-deg pitch between the tractor and carrier bodies. The center wheel assembly, including the differential carrier and the complete suspension system, is attached to the tractor and supported by a bearing forward and aft of the carrier assembly. This assembly can rotate ± 15 deg about the tractor roll axis and is independent of the carrier body in roll and pitch. Lateral pivoting of the carrier is not provided, thus eliminating the possibility of jackknifing of the tractor and carrier. The front and rear wheels are

mechanically connected through the articulation joint to give coordinated front and rear steering.

Test Procedure and Performance Data

13. In all tests, an attempt was made to maneuver the vehicle into a starting position in the water sufficiently far from the bank that the vehicle could attain its maximum speed in the water before contacting the bank, and so that the projected path of the vehicle would be directly in line with the aspect of the bank slope to minimize the steering necessary after the vehicle contacted the bank. The approach to the bank was made in high gear at full power. As near as possible to the anticipated point of contact with the bank, the driver shifted to a lower gear and applied sufficient power throughout the transition from the water to the land to ensure maximum traction. When the vehicle had passed a point one vehicle length from the water's edge, or when it became apparent the vehicle could not proceed to that point, the test was terminated.

14. Pertinent notes describing the test conditions, and especially the ease or difficulty of movement experienced by the vehicle, were made for all tests. In addition, instrumentation installed on the M29C cargo carrier and the M113 amphibious personnel carrier recorded continuous measurements of drive-line torque, right- and left-track revolutions, time, water pressure on cells located below the waterline at the front and rear of the vehicle, angle of pitch as determined by vertical gyroscope, and rate of tagline playout. Some of these data are summarized herein (table D2); the rest are filed for future reference.

Site and Soil Data Obtained

Profiles

15. Two cross-section profiles, one for each wheel or track path, were obtained according to the following controls:

   a. Considering the water's edge as station zero, elevation measurements were taken, proceeding from land into the water, at 1-ft horizontal increments or at points where significant changes occurred in the profile until reaching the water depth at which initial vehicle-bank contact was anticipated. Since the draft of the M113 is 59 in., in Thailand profiles below the water were taken to a depth of 5 ft to standardize data collection procedures.

b. On the land side of the water's edge, elevation measurements were taken as often as necessary to reproduce any feature of the surface that might affect vehicle performance. All abrupt changes in slope were included. Where slope changes were indistinguishable, the elevation measurements were taken at 1-ft increments. The profile was extended upslope a distance equal to at least one vehicle length. To standardize data collection procedures, in Thailand profiles upslope from the water's edge were extended to 20 ft. An example of the layout of profile measurements is shown in fig. D11.

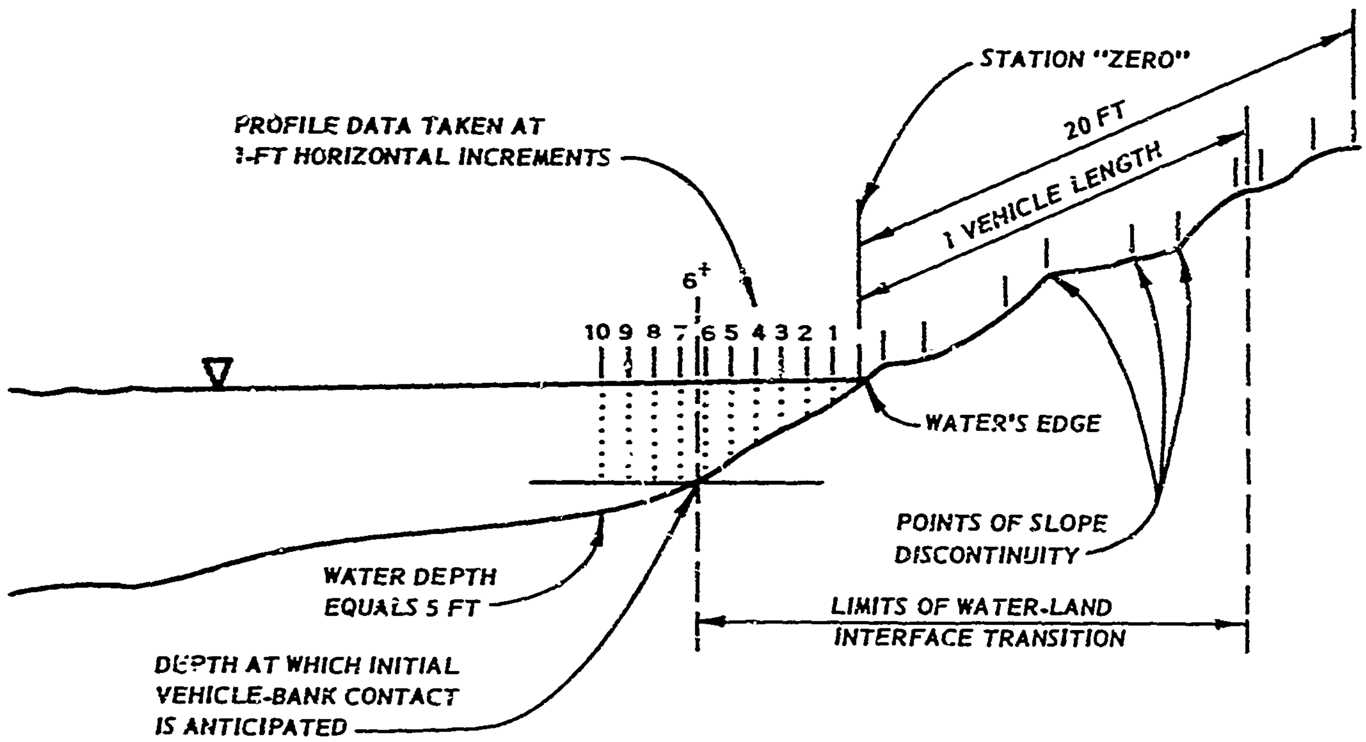


Fig. D11. Layout of profile measurements

Soil

16. Soil measurements were made with the cone penetrometer and sheargraph at sufficiently close intervals on the bank below and above the water surface to adequately describe the conditions of soil strength existing at each site. The following measurements were made:

a. Sheargraph.[3] Surface shear strength measurements were made with the Cohron sheargraph at two or three locations on the land side of the water's edge and at two locations on the aquatic side of the water's edge. Additional measurements were made when deemed necessary. On the aquatic side the measurements were made in water 6 in. or less in depth. The vaned or grousered shear head was used to measure soil strength for those tests involving tracked vehicles, and the rubber-faced shear head was employed for the tests involving the wheeled vehicle. Time was not available for an analysis of these data; however, they are summarized herein (table D2) for possible future use.

b. Cone index. Cone indexes were measured at the surface and at depths of 1, 3, 6, 9, 12, and 18 in. at ten points on the land side and at ten points on the aquatic side of the water's edge at each site. Additional cone indexes were measured when deemed necessary. The average cone indexes for the surface and the 3- and 6-in. depths, and the average for the 0- to 6-in. depths for each site are included in table D2.

c. Bulk samples. Samples for classification of the soil according to the USCS were obtained from the 0- to 12-in. layer for each site.

Other Data Obtained

17. Other data collected included pertinent notes, observations, and photographs.

PART III: TEST RESULTS AND ANALYSIS

18. A preliminary investigation intended to identify the significant physical elements and their interrelations associated with amphibious vehicle transition from water to land was undertaken prior to conduct of field tests. The results of the preliminary investigation indicated that during the period of transition there is a continuous increase in vehicle weight acting normal to the bank commensurate with a continuous decrease in buoyancy force. Stated more simply, as the vehicle emerges from the water the tractive force required to climb the slope of the bank increases; concurrently, the load normal to the slope increases and the tractive force that can be developed increases. Presumably, an incremental analysis could resolve the forces involved at each instant during the water-to-land transition and pinpoint the exact conditions existing at all times. While it is believed that sufficient data were available to permit such a detailed analysis, the development of the complex computer program that would be required was beyond the scope of this investigation. A cursory examination of the field data suggested that a simple analysis, using established procedures, would yield empirical relations of soil strength and slope that might be used to predict performance of similar vehicles in the water-land interface.

Resolution of Forces on a Slope

19. It is assumed that when a vehicle is operating on a slope the maximum tractive force the vehicle can develop is proportional to the maximum tractive force that can be developed on a level in the same ratio as the load normal to the slope to vehicle weight on a level. The equation for the maximum force that can be developed (F_{md}) by a vehicle traveling upslope may be written as

$$F_{md} = T_m\left(\frac{W \cos \theta}{W}\right) = T_m \cos \theta \qquad (1)$$

or since $T_m = DBP + R_s$,

$$F_{md} = DBP \cos\theta + R_s \cos\theta \qquad (2)$$

where

T_m = maximum tractive force on level soil surface, lb

W = vehicle weight, lb

θ = angle of ground surface from the horizontal, deg

DBP = drawbar pull on level soil surface, lb

R_s = motion resistance due to soil on level surface, lb

20. The resisting force due to gravity (F_s) when the vehicle is traveling upslope is equal to that component of vehicle weight exerted parallel to the slope and may be expressed by the equation

$$F_s = W \sin\theta \qquad (3)$$

21. The maximum force required (F_{mr}) for the vehicle to climb the slope may be determined by the equation

$$F_{mr} = W \sin\theta + R_s \cos\theta \qquad (4)$$

22. The maximum slope a vehicle can climb will occur when the maximum force required is just equal to the maximum force that can be developed and may be determined by setting equation 4 equal to equation 2.

$$W \sin\theta + R_s \cos\theta = DBP \cos\theta + R_s \cos\theta$$

Then by reducing

$$\frac{\sin\theta}{\cos\theta} = \frac{DBP}{W}$$

or

$$\tan\theta = \frac{DBP}{W} \qquad (5)$$

23. The concepts of mobility expressed in the general form of the equations above gained acceptance by early investigators in mobility work

and are widely used as a basis for interpreting results of mobility field tests. The results of the tests reported herein are discussed in the following paragraphs.

Tests in Coarse-Grained Soils

24. Five water-land interface tests were conducted with the M29C in the reservoir at Eglin AFB. These tests were intended primarily to acquaint the driver and test personnel with the water-land interface test procedures to be used later in the program in Thailand; hence the data collected were minimal. Since only a small section of the bank was utilized, and since the soil strength appeared to be uniform throughout the area, the same soil strength values were used for all five tests. Fig. D12 shows the M29C attempting to make the water-to-land transition at the Eglin AFB test area.

25. In addition to the test results obtained at Eglin AFB, results of 19 drawbar pull tests conducted with the M29C on level dry-to-moist sand in the vicinity of Vicksburg, Miss., and reported in Technical Memorandum No. 3-240, 17th Supplement,[4] were used in the analysis. Before-traffic

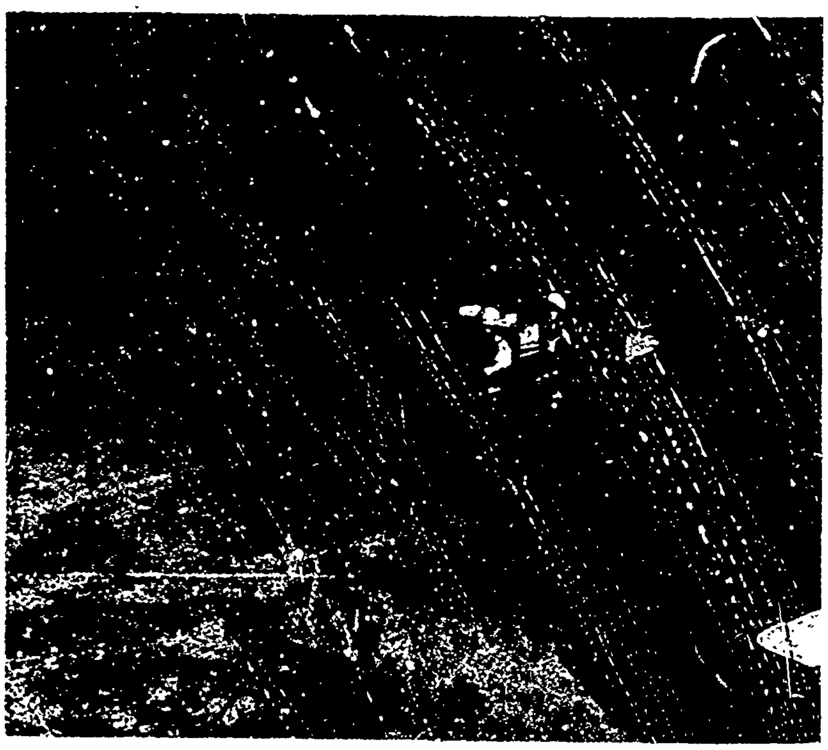


Fig. D12. M29C attempting to make water-to-land transition at Eglin AFB test site cone index for the Eglin AFB tests and first-pass drawbar pull data for the Vicksburg tests are summarized in tables D2 and D3, respectively.

26. The analysis of the results of tests in coarse-grained soils consists of a plot of the tangent of the slope angle θ (for the Eglin AFB tests) and maximum drawbar pull/vehicle weight (for the Vicksburg tests) versus the average 0- to 6-in. cone index. These data are shown graphically in plate D1. The horizontal line representing the average DBP/W value (0.49) for the Vicksburg tests, extended, forms a line of separation between immobilizations and nonimmobilizations for the Eglin tests. Despite the obvious limitations of these tests, it is noteworthy that the two tests in which $\tan\theta >$ average DBP/W resulted in immobilizations and that the tests in which $\tan\theta <$ average DBP/W resulted in nonimmobilizations were as would be expected.

Tests in Fine-Grained Soils

27. For this part of the study, 35 water-land interface tests were conducted with two tracked and one wheeled vehicle in the vicinity of Khon Kaen on fine-grained soils: 9 tests were conducted with the M29C cargo carrier, 18 tests with the M113 personnel carrier, and 8 tests with the XM561 articulated cargo truck. Data for these tests are summarized in table D2. Available drawbar pull, slope, and soil strength data for wet-surface conditions previously reported in other studies were also used in the analysis, and the data were analyzed in much the same manner as that for the coarse-grained soil tests. Although previous trafficability studies[5] in fine-grained soils have related the drawbar pull and the slope-climbing performance of vehicles for 40 to 50 passes to the strength of a subsurface "critical layer" (3- to 9-in., 6- to 12-in., or 9- to 15-in. layer, dependent upon vehicle weight), more recent effort and work in progress have suggested that one-pass performance in the same terms may be more closely allied with the soil strength nearer the surface. Accordingly, the average 0- to 6-in. cone index was selected as the parameter to represent soil strength in this analysis.

Performance of the M29C

28. For the M29C, sufficient data were available to examine the effect of soil strength (CI) on drawbar pull and slope-climbing performance. The results of the analysis are discussed in the following paragraphs.

29. Mississippi tests. Results of 11 tests conducted on level, wet areas were used in developing drawbar pull-soil strength relations for fine-grained soils. These tests were conducted at Grenada Lake, Miss., and are reported in WES Contract Report No. 3-152.[6] Before-traffic cone index and first-pass drawbar pull data used in the analysis are summarized in table D4. A plot of maximum drawbar pull expressed as a ratio to vehicle weight versus the average 0- to 6-in. cone index is shown in fig. a, plate D2. The curve drawn through the data points represents the line of best visual fit. Note that the curve is extrapolated, as indicated by the dashed line, to the zero drawbar pull point (i.e., the minimum soil strength required for one pass on a level surface). This value, CI = 9 , was determined on the basis of tests in other programs and work currently in progress.

30. Thailand tests. The test results for the nine water-land interface tests conducted in Thailand wherein the vehicle climbed various slopes while exiting water bodies are summarized in table D2. Fig. D13 shows three tests in progress. A plot of the tangent of the slope angle versus the average 0- to 6-in. cone index for these tests is shown in fig. b, plate D2. The drawbar pull-soil strength curve from fig. a, plate D2, has been drawn on fig. b, plate D2, to form a line of separation between the immobilizations and the nonimmobilizations. Two tests, 134 and 136, in which immobilization did not occur fall above the line of separation where it would be expected that the combination of slope and soil strength would immobilize the vehicle. Referring to table D2, it may be seen that in test 134, the recorded slip for the test was 44.6 percent, indicating that the vehicle was proceeding with considerable difficulty. It may be further seen from table D2 that the 44.6 percent slip for test 134 was the highest slip recorded for any M29C tests, barring the immobilizations, of course. Again referring to table D2, it may be noted that the vehicle was partially floating when it crossed the maximum slope in test 136; hence, the maximum

a. M29C immobilized in the water-land interface at test site 5-H-8, Thailand

b. M29C negotiating the water-land interface at test site 5-H-3 Thailand

c. M29C negotiating the water-land interface at test site 5-H-4, Thailand

Fig. D13. Three M29C tests in progress near Khon Kaen attitude angle of the vehicle was somewhat less than the maximum slope angle. In both cases, moreover, the points are not unacceptably distant from the line of separation.

Performance of the M113

31. Thailand tests. The results of 18 water-land interface tests conducted near Khon Kaen with the M113 are summarized in table D2. Fig. D14 shows a test in progress. A plot of the tangent of the slope angle versus the average 0- to 6-in. cone index is shown in fig. a, plate D3. The minimum soil strength required for one pass on a level surface is indicated to be at CI = 13 ; this value was determined on the basis of tests in other programs and work now in progress. No drawbar pull data were available for the M113 personnel carrier in fine-grained soils with wet surfaces; therefore the drawbar pull-soil strength curve for the M29C from fig. a, plate D2, was superimposed on this plot using the minimum soil strength required for one pass of the M113 (CI = 13) as the starting point. In other words, the curve drawn on fig. a, plate D3, is the curve from fig. a, plate D2, shifted 4 cone index points to the right. By way of explanation of the use of the M29C curve displaced to represent the performance of the M113, it may be pointed out that in Technical Memorandum No. 3-240, 14th Supplement,[5] Knight presents an average curve for all tracked vehicles with grousers less than 1-1/2 in., using as a strength parameter the soil strength above minimum soil strength required, which is of course equivalent to repetition of the same curve intersecting a constant soil strength axis at various minimum soil strengths. It may be further pointed out that the M29C and the M113 are both relatively lightweight vehicles of generally similar configuration.

32. As a line of separation between immobilizations and nonimmobolizations, this curve appears to fit the data acceptably. It may be noted from fig. a, plate D3, that two points fall on the wrong side of the line of separation; however, they are so close to the line of separation that no justification appears necessary.

33. Panama tests. As stated above, no drawbar pull data were available for the M113 personnel carrier in fine-grained soils with wet surfaces; however, some fine-grained soil, slope-climbing test data on wet

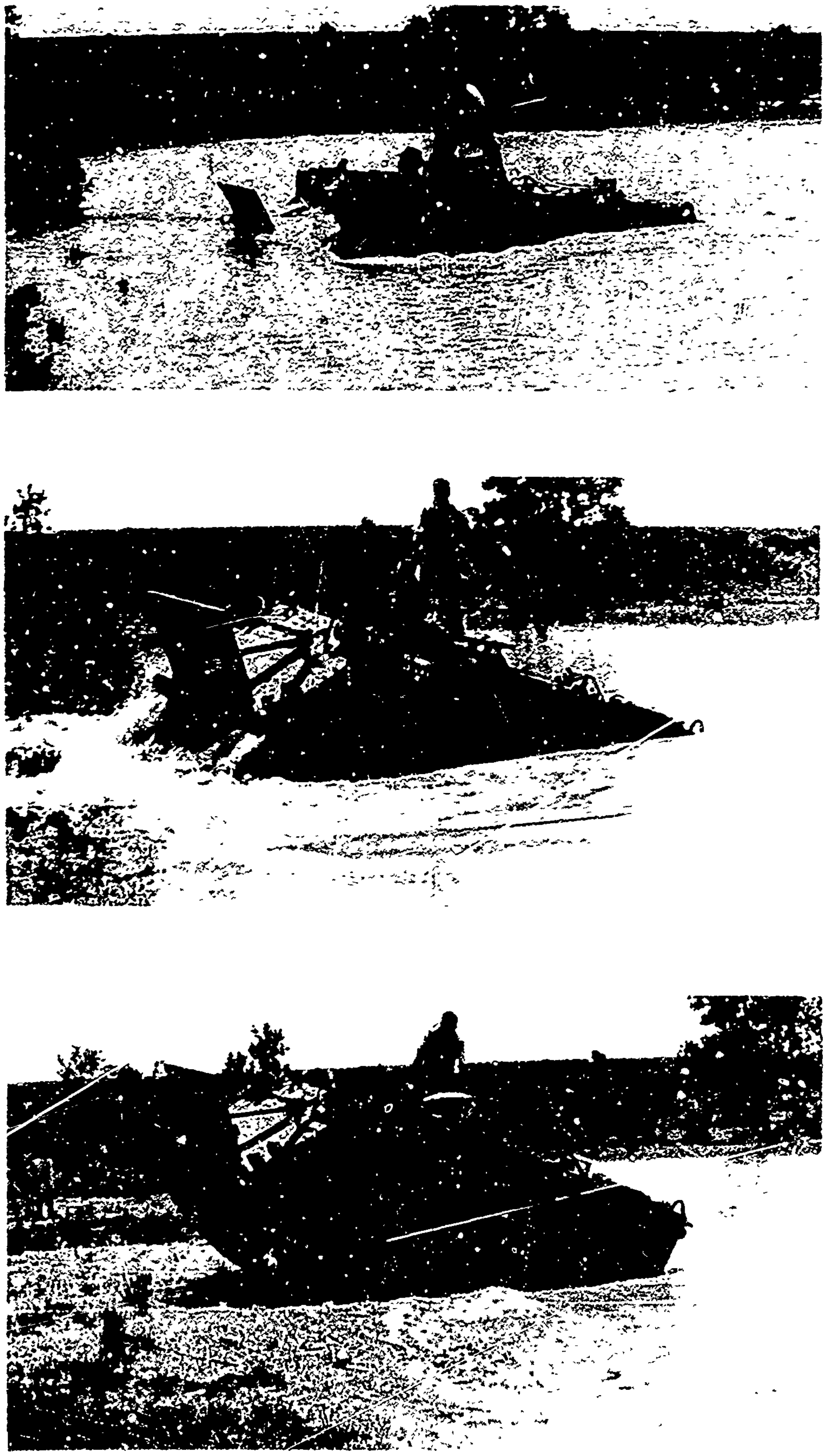


Fig. D14. M113 operating in water-land interface at site 5-H-4 near Khon Kaen surface soils were available for tests conducted with the M113 in Panama,[7] and they have been included in the data analysis. The analysis performed and the rationale involved is the same as that discussed for M113 tests conducted in Thailand.

34. Twelve tests conducted in Panama were used in the analysis, and the data are summarized in table D5. A plot of the tangent of the slope angle versus the average 0- to 6-in. cone index for the Panama tests is shown in fig. b, plate D3. The drawbar-soil strength curve from fig. a, plate D2, shifted to the right to intercept the abscissa at the minimum soil strength required for one pass (CI = 13), serves as the line of separation between immobilizations and nonimmobilizations. It may be seen from fig. b, plate D3, that only one point, test 7, falls on the wrong side of the line of separation. The field notes for this test indicate that sticks and branches were placed on this slope to serve as traction aids and that the slope was relatively short. In the cited report, the authors state that "In many cases, successful negotiation of a short slope was aided by a running start."

Performance of the XM561

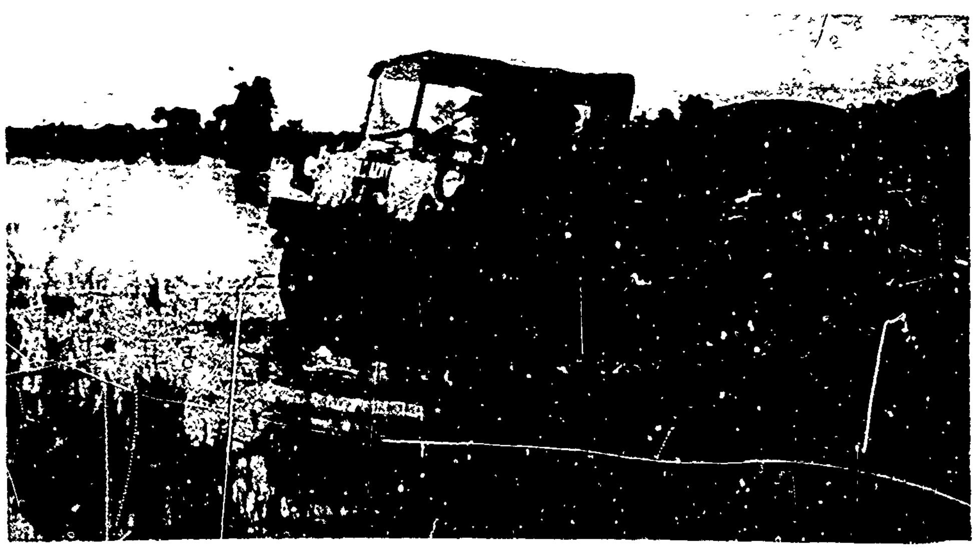
35. Eight tests were conducted in fine-grained soils with the XM561 at test sites located south of Khon Kaen. Test data are summarized for each test in table D2. The data were analyzed in the same manner as that for the tracked vehicle tests and consisted of plotting the tangent of the maximum slope angle for each water-land interface test versus the average 0- to 6-in. cone index (see plate D4). The minimum soil strength required for one pass was computed by a semiempirical method* developed and now being evaluated by WES. The curve of best visual fit was drawn separating the immobilizations from the nonimmobilizations using the one-pass soil strength as a starting point. A search for comparative tests with this vehicle was unrewarding; thus due to the paucity of test results, especially in the critical 20 to 80 cone index range, the curve must be

* Work in progress and curves relating a computed mobility index to the vehicle cone index required for one pass and fifty passes of a vehicle on level soil are described in "Quarterly Progress Report on Waterways Experiment Station Research and Development Projects" for the first quarter of 1969.

regarded with caution. Nevertheless, it is believed that the curve indicates a reasonable approximation of the performance of the XM561 in the water-land interface.

36. From observations made during the XM561 tests it was noted that articulation is an important factor in making the transition from water to land. The articulation joint allows the front unit of the XM561 to conform to the shape of the interface immediately upon contact with the bank, thus putting four wheels in contact with the bank surface at the most critical time during the transition phase. It was observed during the tests that at least some kinetic energy obtained from water speed was frequently necessary to start the XM561 up the bank. Fig. D15 shows the XM561 operating in the water-land interface.

a. XM561 immobilized in water-land interface at site 5-H-4



b. XM561 negotiating the water-land interface at site 5-H-6

Fig. D15. Two XM561 tests in progress near Khon Kaen

Comparison of the performance
of tracked and wheeled vehicles

37. The performance curves for the three vehicles are shown in plate D5. To collapse the curves of the tracked vehicles and to facilitate comparison, the abscissa of the plot is in terms of cone index points above minimum soil strength required for one pass (VCI_1). It may be seen from the curves in plate D5 that a small increase in strength above the minimum required for one pass resulted in a larger increase in performance for the wheeled vehicle than for the tracked vehicles. This has been frequently observed in field tests, and no satisfactory explanation has yet been obtained.

Notes and Observations

38. While it is believed that the curves in plate D5 do represent the performance of the vehicles tested in this program and may be used to predict the performance of these or similar vehicles in analogous terrain, the reader is reminded that the soil strength data are rather limited, that relatively few tests reflect combinations of soil strength and slope that are in close proximity to the line of separation between go or no-go condition, and that the effect of kinetic energy may have enabled the vehicles to negotiate some shorter slopes that would otherwise have resulted in immobilizations.

39. The study and definition of the interrelations of forces acting on an amphibious vehicle leaving the water, and the results of the limited number of field tests conducted, indicate the performance of amphibious vehicles making the water to land transition is largely dependent upon the amount of tractive force that the subaqueous soils will sustain. Previous studies of soil-vehicle systems have revealed that the tractive force a vehicle can develop in weak soils is, in turn, largely a function of (a) the normal stress (in psi) a vehicle's tractive elements apply to the ground (η), and (b) the gross area (A_c) over which the normal stress is applied. During the water to land transition, η and A_c vary continuously until the vehicle emerges completely from the water; consequently performance and the factors affecting it are continuously changing as the vehicle goes from a free-floating condition to emergence on dry land.

PART IV: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

40. Based on the analysis of the data herein, and subject to the limits imposed by these data, the following conclusions are offered:

- a. The performance of tracked and wheeled vehicles in terms of "go-no go" in the water-land interface can be empirically correlated with the soil strength expressed in terms of the average cone index of the 0- to 6-in. soil layer (paragraphs 26, 30, 31, and 35).
- b. The slope-climbing performance of the M113 and M29C in the water-land interface compares favorably with that of the same vehicles operating on land surfaces of similar soil composition and consistency (paragraphs 29, 30, and 34).

Recommendations

41. It is recommended that:

- a. Additional studies be conducted to improve and extend the relations presented in this report, and to develop relations that account for all significant factors having an effect on vehicle performance in entering and exiting water bodies.
- b. The mathematical model developed for use in predicting cross-country vehicle performance include provisions for predicting performance of amphibious vehicles in the water-land interface.

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Table D1

Summary of Soil Classification Data

for 0- to 12-in. Layer

Site No.	Grain Size, % by Weight: Gravel Coarse	Gravel Fine	Sand Coarse	Sand Medium	Sand Fine	% Fines	Atterberg Limits*: LL	PL	PI	USCS Soil Type	Soil Description
						Eglin AFB					
E-H-5	0	0	2	25	61	12	--	--	NP	SP-SM	Silty medium-to-fine sand
						Khon Kaen					
5-H-1 E	0	0	1	2	1	96	58	27	31	CH	Clay
5-H-1 W	0	0	1	7	6	86	38	20	18	CL	Sandy clay
5-H-2	0	0	2	3	29	66	31	17	14	CL	Sandy clay
5-H-3	0	0	0	6	4	90	77	38	39	MH	Clayey silt
5-H-4	0	0	0	4	6	90	69	37	32	MH	Clayey silt
5-H-5	0	0	0	7	20	73	71	35	36	MH	Sandy silt
5-H-6	0	0	0	2	5	93	38	21	17	CL	Lean clay
5-H-7	0	4	4	5	20	67	24	18	6	CL-ML	Silty clay
5-H-8	0	0	1	3	3	93	--	--	NP	ML	Silt
5-H-10	0	2	0	1	7	90	40	23	17	CL	Sandy clay

* LL = liquid limit; PL = plastic limit; PI = plasticity index.

Table D2

Summary of Data and Test Results, Water-Land Interface Tests with Amphibious Vehicles

Site No.	Test No.	1965 Date	Bank Slope Angle deg	Bank Slope Tangent of Angle	Track Slip %	Avg Cone Index at Depth, in. 0	3	6	0-6	Sheargraph* Below Water c, psi	Below Water tan Ø	On Land c, psi	On Land tan Ø	Test Results	
															M113 (Test Weight 22,018 lb), Tests Conducted near Khon Kaen in Fine-Grained Soils
5-H-2	84	15 Sept	6.0	0.11	27.7	17	86	126	76	2.0	0.41	2.9	0.41	Not immobilized	Pressure cell data not valid
5-H-1 W	85	15 Sept	14.4	0.25	42.8	13	203	272	163	1.4	0.12	3.3	0.32	Not immobilized	
5-H-5	86	15 Sept	16.0	0.29	41.1	12	124	214	117	2.0	0.44	4.3	0.65	Not immobilized	
5-H-5	87	15 Sept	16.8	0.30	37.5									Not immobilized	Slope was difficult to negotiate
5-H-4	88	15 Sept	20.8	0.38	33.8									Not immobilized	Initial contact of the uneven bank angle of approximately 30 deg. Th
5-H-4	89	15 Sept	22.8	0.42	100.0	15	173	238	143	1.4	0.23	2.1	0.47	Immobilized	
5-H-4	90	16 Sept	20.8	0.38	47.0									Not immobilized	
5-H-4	91	16 Sept	22.8	0.42	100.0									Immobilized	The vehicle was immobilized with fro
5-H-4	92	16 Sept	20.8	0.38	47.1									Not immobilized	Test engineer stated that momentum a slightly to the left after encount
5-H-3	93	16 Sept	20.5	0.37	48.6	35	301	330	222	0.4	0.17	1.0	0.28	Not immobilized	Vehicle veered slightly to the left
5-H-3	94	16 Sept	19.3	0.35	43.3									Not immobilized	The gyroscope data are questionable
5-H-1 E	95	16 Sept	6.9	0.12	7.5	62	136	139	12	--	--	--	--	Not immobilized	Initial contact of the uneven bank b
5-H-6	96	16 Sept	22.3	0.41	45.8									Not immobilized	
5-H-6	97	16 Sept	21.8	0.40	50.0	29	136	179	115	0.0	0.17	1.5	0.31	Not immobilized	Forward motion of the vehicle stoppe The driver disengaged the power tr vehicle in a forward gear and comp
5-H-6	98	16 Sept	[illegible]	0.41	48.2									Not immobilized	
5-H-8	101	16 Sept	32.6	0.64	100.0	67	158	189	138	0.0	0.22	1.3	0.48	Immobilized	Generator supplying power to the ins
5-H-8	102	16 Sept	31.2	0.60	100.0									Immobilized	
5-H-7	103	16 Sept	34.2	0.68	100.0	22	175	284	160	1.2	--	2.3	0.42	Immobilized	
															M29C (Test Weight 6100 lb), Tests Conducted near Khon Kaen in Fine-Grained Soils
5-H-2	130	24 Sept	7.5	0.13	0.0	28	113	186	109	1.2	0.20	1.5	0.38	Not immobilized	Vehicle made the transition with no
5-H-5	131	24 Sept	19.9	0.36	27.7	16	146	243	135	2.0	0.46	1.7	0.52	Not immobilized	The driver experienced difficulty sh came to a complete stop on the slo
5-H-5	132	24 Sept	19.9	0.36	0.0									Not immobilized	The vehicle stopped momentarily when exit
5-H-4	133	24 Sept	23.7	0.44	0.0	24	152	313	163	0.6	0.44	4.0	0.12	Not immobilized	
5-H-4	134	24 Sept	24.0	0.45	44.6	← Same as test 88 →								Not immobilized	
5-H-3	135	24 Sept	22.8	0.42	15.5	← Same as test 93 →								Not immobilized	
5-H-6	136	24 Sept	24.2	0.45	0.0	23	157	207	129	0.0	0.22	0.4	0.17	Not immobilized	Vehicle was partially floating at po
5-H-8	137	24 Sept	29.9	0.58	100.0	33	161	225	140	1.2	0.37	2.1	0.52	Immobilized	
5-H-10	138	24 Sept	28.6	0.54	100.0									Immobilized	The test conditions were very satisf
															M29C (Test Weight 5600 lb), Tests Conducted at Eglin AFB in Coarse-Grained Soils
E-H-5	316	16 Apr	24.3	0.45	--									Not immobilized	
E-H-5	317	16 Apr	27.0	0.51	100.0									Immobilized	
E-H-5	318	16 Apr	14.0	0.25	--	5	15	18	13	--	--	0.0	0.29	Not immobilized	The engine stalled on the first atte as the driver shifted to a lower g
E-H-5	319	16 Apr	26.6	0.50	100.0									Immobilized	
E-H-5	320	16 Apr	22.8	0.42	--									Not immobilized	Water washed over the top of the re making the transition
															XM561 (Test Weight 9480 lb), Tests Conducted near Khon Kaen in Fine-Grained Soils
5-H-5	188	2 Oct	20.8	0.38	--	← Same as test 131 →								Immobilized	The vehicle was immobilized on three
5-H-4	189	2 Oct	22.3	0.41	--	← Same as test 133 →								Immobilized	The vehicle was immobilized on two
5-H-1 W	190	2 Oct	18.8	0.34	--	20	190	300+	170+	--	--	--	--	Not immobilized	The vehicle easily negotiated the s
5-H-1 E	191	2 Oct	15.2	0.27	--	← Same as test 95 →								Not immobilized	The vehicle easily negotiated the s
5-H-1 W	192	2 Oct	18.3	0.33	--									Not immobilized	
5-H-2	195	2 Oct	11.9	0.21	--	5	30	56	30	--	--	--	--	Not immobilized	
5-H-6	196	2 Oct	17.8	0.32	--	32	81	141	85	--	--	--	--	Not immobilized	
5-H-7	197	2 Oct	17.8	0.32	--	32	80	143	85	--	--	--	--	Not immobilized	The vehicle completed the transitio

* Values given for sheargraph are c, cohesion; tan Ø, friction angle.

Table D2

Summary of Data and Test Results, Water-Land Interface Tests with Amphibious Vehicles

	Sheargraph*					
	Below Water		On Land			
...6	c, psi	tan Ø	c, psi	tan Ø	Test Results	General Test Notes
M113 (Test Weight 22,018 lb), Tests Conducted near Khon Kaen in Fine-Grained Soils						
76	2.0	0.41	2.9	0.41	Not immobilized	Pressure cell data not valid
63	1.4	0.12	3.3	0.32	Not immobilized	
17	2.0	0.44	4.3	0.65	Not immobilized	
					Not immobilized	Slope was difficult to negotiate
43	1.4	0.23	2.1	0.47	Not immobilized	Initial contact of the uneven bank with the left track caused the vehicle to exit at an oblique angle of approximately 30 deg. The distance-measuring device did not operate properly
					Immobilized	
					Not immobilized	
					Immobilized	The vehicle was immobilized with front portion of tracks out of the water
					Not immobilized	Test engineer stated that momentum aided the vehicle in making the transition. The vehicle veered slightly to the left after encountering the bank
22	0.4	0.17	1.0	0.28	Not immobilized	Vehicle veered slightly to the left after encountering the bank
					Not immobilized	The gyroscope data are questionable
12	--	--	--	--	Not immobilized	Initial contact of the uneven bank by the right track caused the vehicle to veer slightly to the left
115	0.0	0.17	1.5	0.31	Not immobilized	
					Not immobilized	Forward motion of the vehicle stopped at one point in the transition when track slip reached 100%. The driver disengaged the power train and let the vehicle roll backward a few inches, then put the vehicle in a forward gear and completed the exit without difficulty
					Not immobilized	
138	0.0	0.22	1.3	0.48	Immobilized	Generator supplying power to the instrumentation system failed before test was completed
					Immobilized	
160	1.2	--	2.3	0.42	Immobilized	
M29C (Test Weight 6100 lb), Tests Conducted near Khon Kaen in Fine-Grained Soils						
109	1.2	0.20	1.5	0.38	Not immobilized	Vehicle made the transition with no difficulty
135	2.0	0.46	1.7	0.52	Not immobilized	The driver experienced difficulty shifting to a lower gear after contact with the bank. The vehicle came to a complete stop on the slope before the driver engaged the lower gear
					Not immobilized	The vehicle stopped momentarily when the driver shifted to a lower gear, but easily completed the exit
163	0.6	0.44	4.0	0.12	Not immobilized	
Same as test 88 →					Not immobilized	
Same as test 93 →					Not immobilized	
129	0.0	0.22	0.4	0.17	Not immobilized	Vehicle was partially floating at point of maximum slope angle
140	1.2	0.37	2.1	0.52	Immobilized	
					Immobilized	The test conditions were very satisfactory, but the slope was too steep for the vehicle to climb
M29C (Test Weight 5600 lb), Tests Conducted at Eglin AFB in Coarse-Grained Soils						
13	--	--	0.0	0.29	Not immobilized	
					Immobilized	
					Not immobilized	The engine stalled on the first attempt to make the transition, but the second attempt was successful as the driver shifted to a lower gear immediately before contact with the bank
					Immobilized	
					Not immobilized	Water washed over the top of the rear of the tank as the vehicle reached a maximum attitude in making the transition
XM561 (Test Weight 9480 lb), Tests Conducted near Khon Kaen in Fine-Grained Soils						
Same as test 131 →					Immobilized	The vehicle was immobilized on three attempts with the front wheels out of the water
Same as test 133 →					Immobilized	The vehicle was immobilized on two attempts with the front wheels out of the water
170+	--	--	--	--	Not immobilized	The vehicle easily negotiated the slope
Same as test 95 →					Not immobilized	The vehicle easily negotiated the slope
					Not immobilized	
30	--	--	--	--	Not immobilized	
85	--	--	--	--	Not immobilized	
85	--	--	--	--	Not immobilized	The vehicle completed the transition with very little difficulty

...n angle.

B

Table D3

Summary of Data and Test Results, M29C (Test Weight 5560 lb) on Coarse-Grained Soil (SP)*

Item No.	Test No.	Avg Cone Index 0- to 6-in. Layer	DBP/W
1	66	129	0.50
2	67	147	0.50
3	68	134	0.48
4	69	126	0.48
5	70	133	0.49
6	71	112	0.49
7	72	115	0.49
8	73	131	0.48
9	74	125	0.48
10	75	98	0.50
11	76	127	0.50
12	78	151	0.50
13	79	137	0.50
14	80	131	0.48
15	81	142	0.50
16	82	135	0.50
17	83	134	0.50
18	84	141	0.50
19	85	140	0.50
		Average	0.49

* From Technical Memorandum No. 3-240, 17th Supplement.[4]

Table D4

Summary of Data and Test Results, M29C (Test Weight 5960 lb) on Fine-Grained Soil (ML)*

Test Code and No.	Avg Cone Index at Depth, in. 0	3	6	0-6	DBP/W	Remarks
12606	14	43	74	44	0.31	Surface bare, some surface water, one max pull
12706	14	38	60	37	0.23	Surface bare, some surface water, one max pull
12806	18	42	62	41	0.26	Surface bare, some surface water, avg of two pulls
12906	17	44	62	41	0.26	Surface bare, some surface water, one max pull
13006	16	44	54	38	0.26	Surface bare and wet, avg of two pulls
13106	14	40	48	34	0.27	Surface bare and wet, avg of two pulls
14108	23	104	137	88	0.34	Surface bare and wet, one max pull at 35% slip
14208	38	121	152	104	0.40	Surface bare and wet, one max pull at 30% slip
14308	24	112	116	84	0.34	Surface bare and wet, one max pull at 35% slip
16611	65	294	257	205	0.48	80% veg cover, surface damp, avg of nine pulls
17611	58	224	189	157	0.50	Surface bare and damp, avg of nine pulls

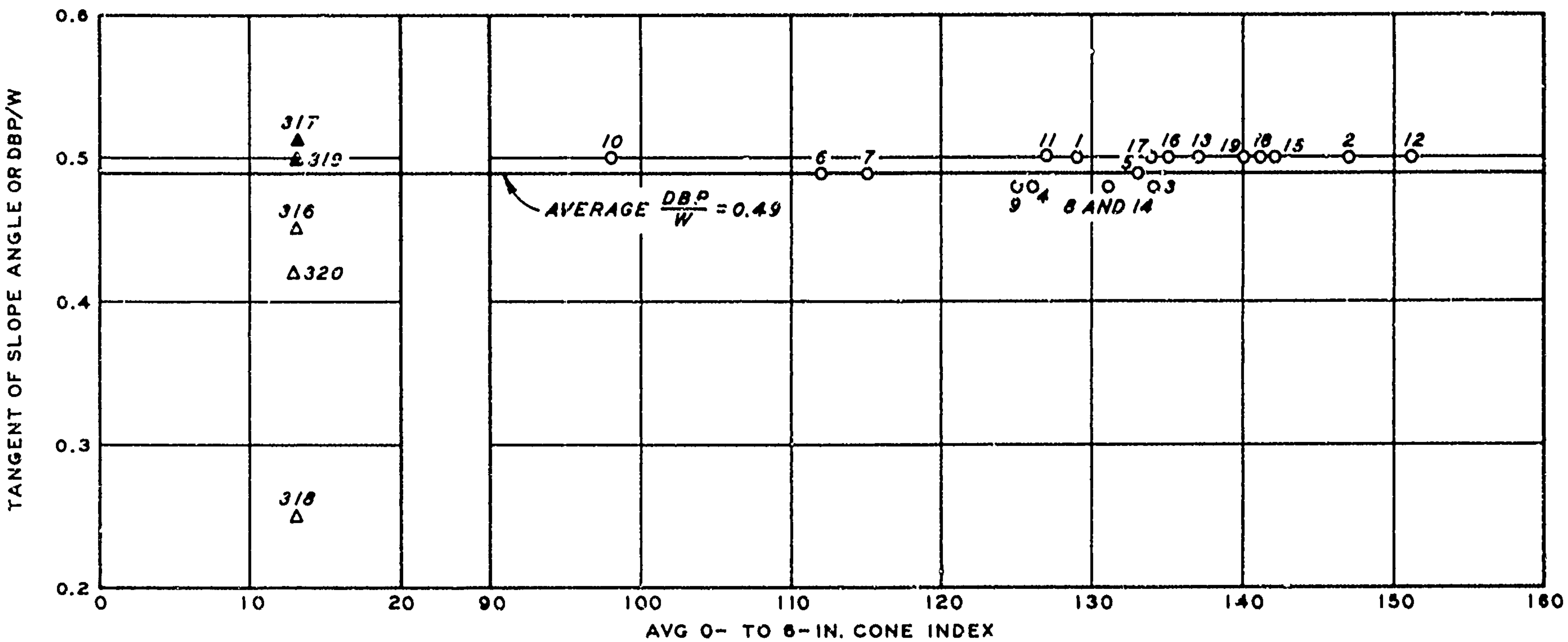
* From Contract Report No. 3-152.[6]

Table D5

Summary of Data and Test Results, M113 (Test Weight 21,000 lb) on Sandy Silts (MH) and Fat Clays (CH)*

Test No.	USCS Soil Classi-fication	Tangent of Slope Angle	Avg Cone Index 0- to 6-in. Layer	Test Results	Remarks
1B	CH	0.00	11	Immobilized	Surface wet
7	MH	0.43	76	Not immobilized	Rained 10 min prior to testing
9	MH	0.28	79	Not immobilized	Raining during test
14	MH	0.13	58	Not immobilized	Surface wet
20	MH	0.59	78	Immobilized	Surface wet
21	MH	0.43	78	Immobilized	Surface wet
30	CH	0.53	75	Immobilized	Surface wet
39	MH	0.32	74	Not immobilized	Surface wet
40	MH	0.58	93	Immobilized	Surface wet
41	MH	0.59	152	Immobilized	Surface wet
47	MH	0.30	51	Not immobilized	Surface wet
48	MH	0.52	69	Immobilized	Surface wet

* From Technical Report No. 3-609.[7]



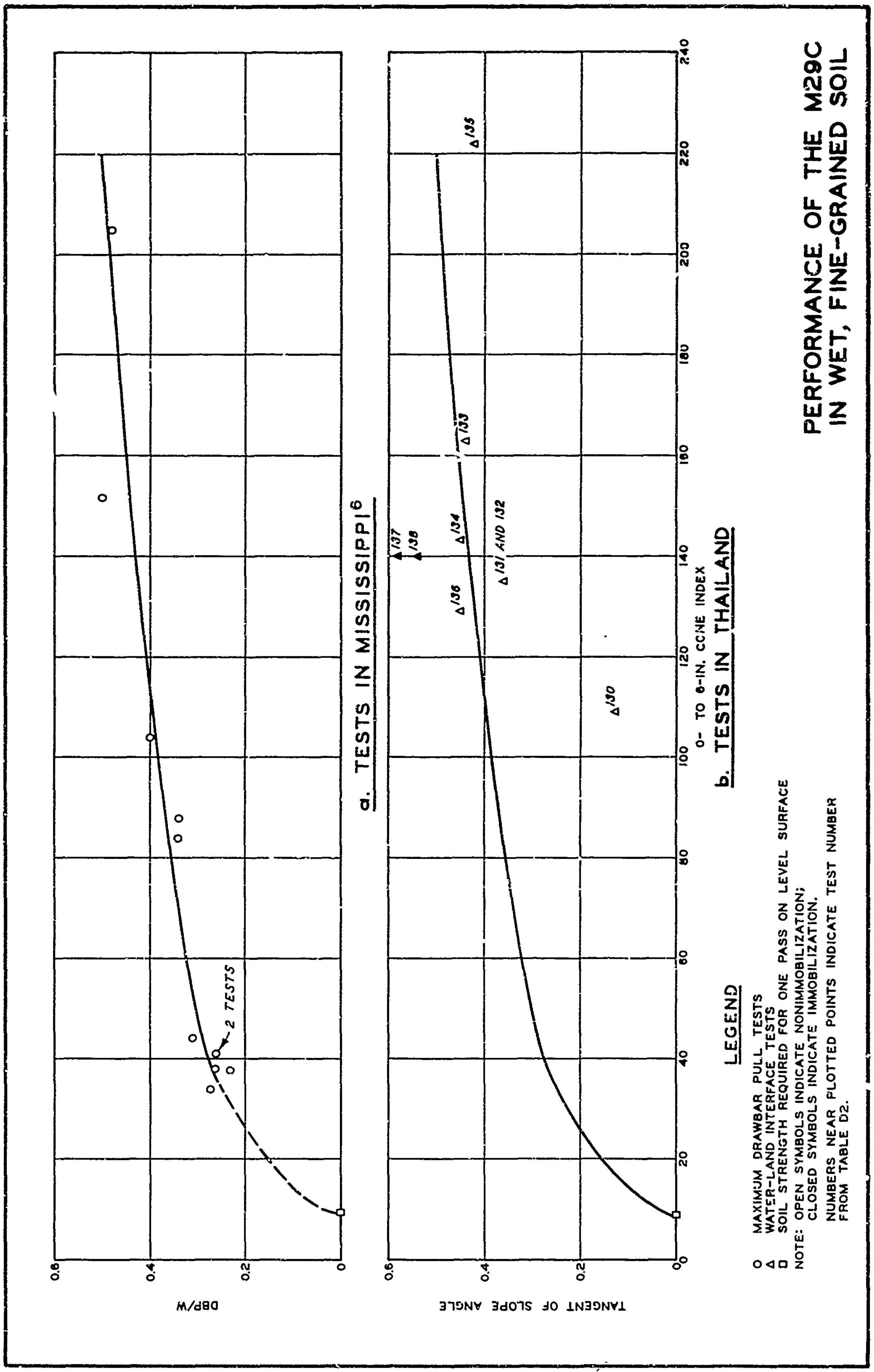
LEGEND

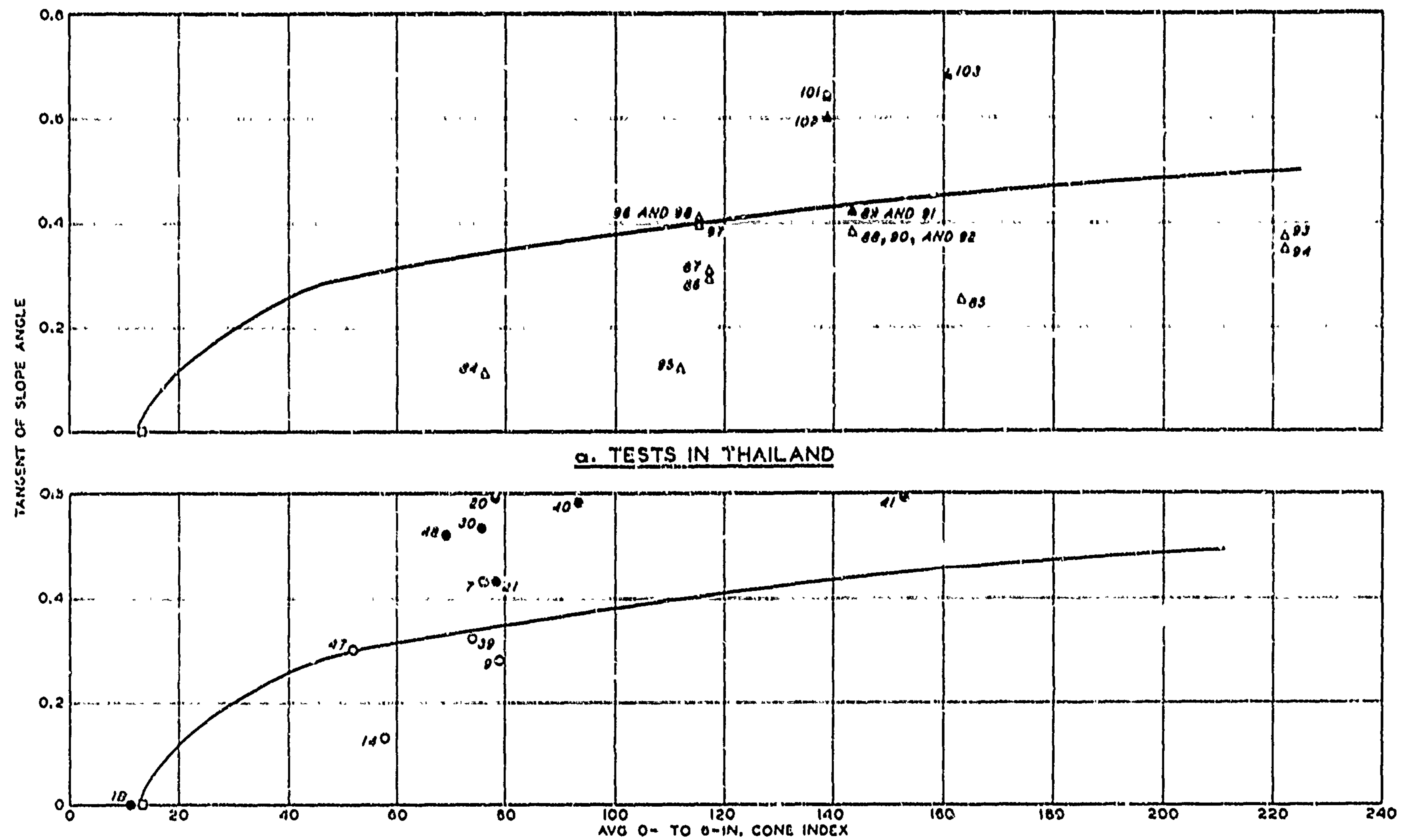
O MAXIMUM DRAWBAR PULL TESTS

Δ WATER-LAND INTERFACE TESTS

NOTE: OPEN SYMBOLS INDICATE NONIMMOBILIZATION; CLOSED SYMBOLS INDICATE IMMOBILIZATION.
NUMBERS NEAR PLOTTED CIRCLES INDICATE ITEM NUMBER FROM TABLE D3.
NUMBERS NEAR PLOTTED TRIANGLES INDICATE TEST NUMBER FROM TABLE D2.

PERFORMANCE OF M29C IN COARSE-GRAINED SOIL


PERFORMANCE OF THE M29C
IN WET, FINE-GRAINED SOIL
a. TESTS IN MISSISSIPPI[6]
b. TESTS IN THAILAND
DBP/W
TANGENT OF SLOPE ANGLE
0- TO 6-IN. CONE INDEX
2 TESTS
137
138
134
133
135
136
131 AND 132
130
0
0.2
0.4
0.6
20
40
60
80
100
120
140
160
180
200
220
240
LEGEND
○ MAXIMUM DRAWBAR PULL TESTS
△ WATER-LAND INTERFACE TESTS
□ SOIL STRENGTH REQUIRED FOR ONE PASS ON LEVEL SURFACE
NOTE: OPEN SYMBOLS INDICATE NONIMMOBILIZATION;
CLOSED SYMBOLS INDICATE IMMOBILIZATION.
NUMBERS NEAR PLOTTED POINTS INDICATE TEST NUMBER
FROM TABLE D2.



a. TESTS IN THAILAND

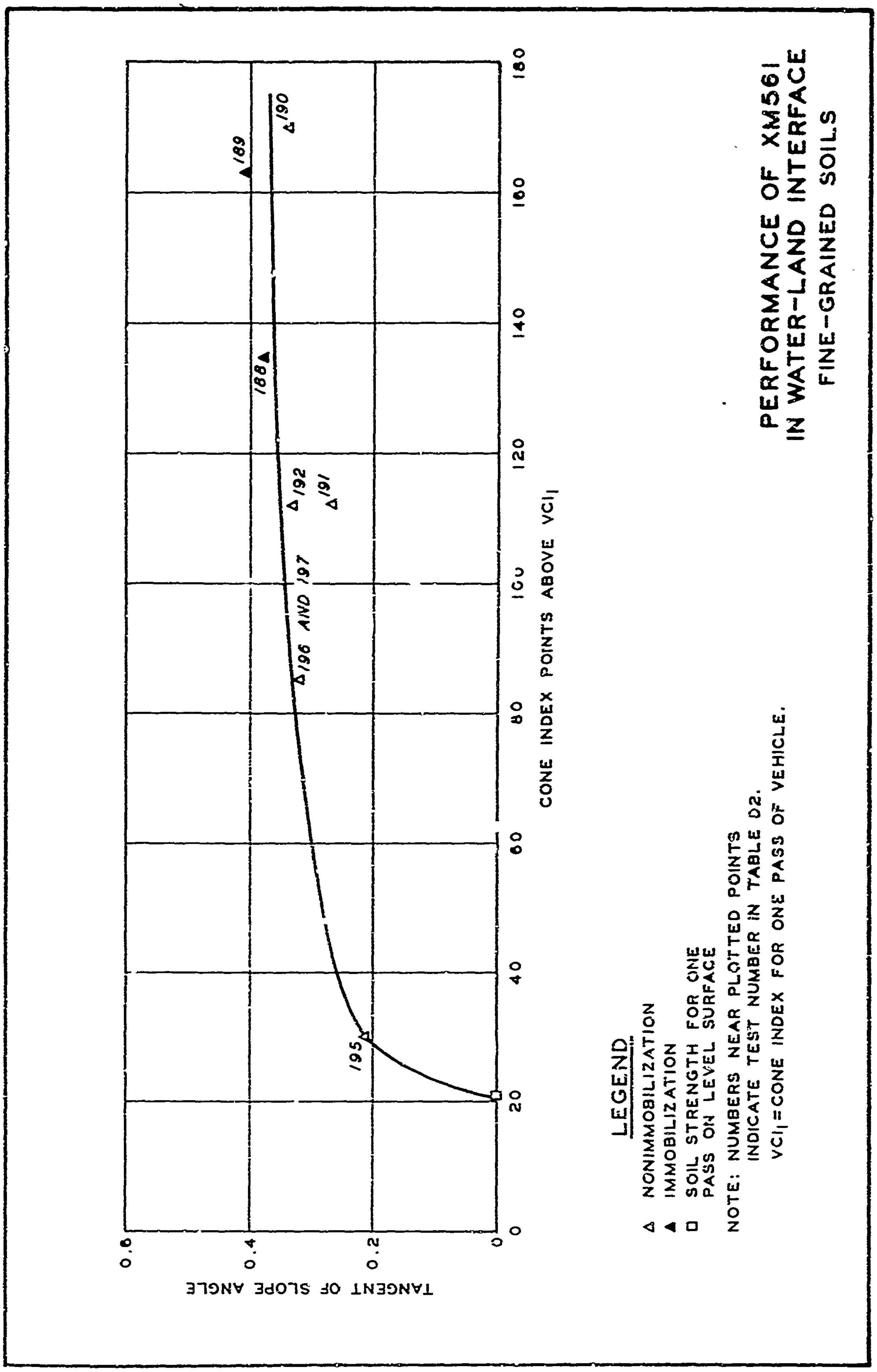
b. TESTS IN PANAMA

LEGEND

- O SLOPE-CLIMBING TESTS
- Δ WATER-LAND INTERFACE TESTS
- □ SOIL STRENGTH REQUIRED FOR ONE PASS ON LEVEL SURFACE

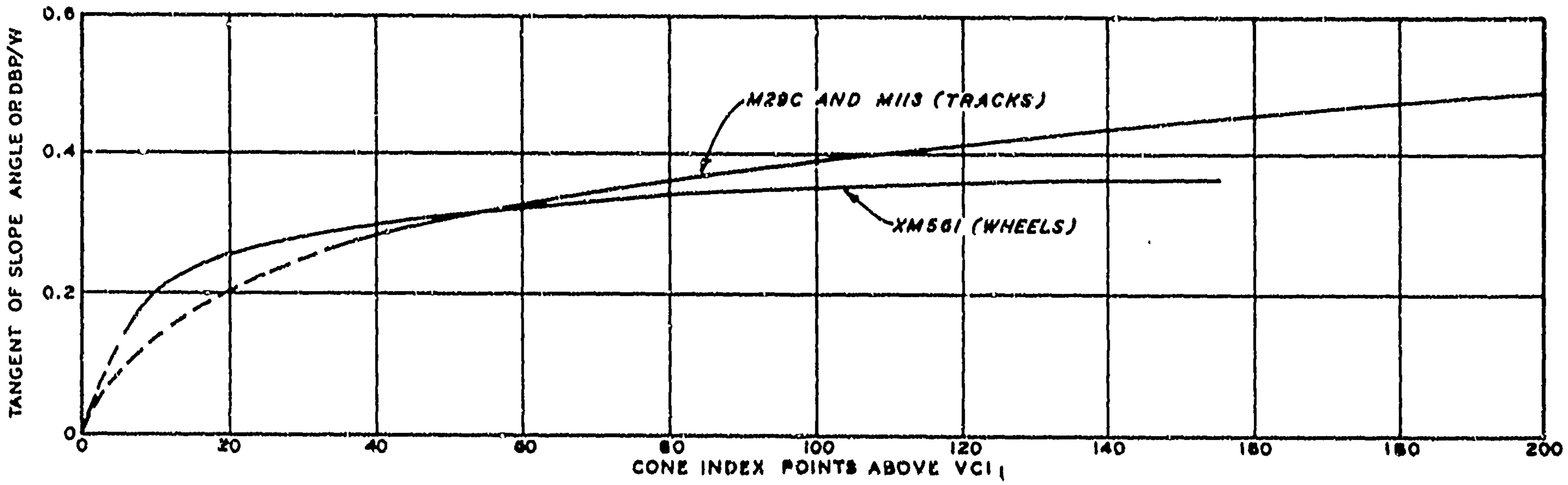
NOTE: OPEN SYMBOLS INDICATE NONIMMOBILIZATION;
CLOSED SYMBOLS INDICATE IMMOBILIZATION.
NUMBERS NEAR PLOTTED CIRCLES INDICATE TEST NUMBER FROM TABLE D5.
NUMBERS NEAR PLOTTED TRIANGLES INDICATE TEST NUMBER FROM TABLE D2.

PERFORMANCE OF THE M113
IN WET, FINE-GRAINED SOIL



PERFORMANCE OF XM561
IN WATER-LAND INTERFACE
FINE-GRAINED SOILS

PLATE D4



NOTE: VCI_1 = CONE INDEX FOR ONE PASS OF VEHICLE.

PERFORMANCE OF TRACKED AND WHEELED VEHICLES IN THE WATER-LAND INTERFACE

FINE-GRAINED SOILS

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13. ABSTRACT

Forty tests were conducted with two amphibious tracked vehicles and one amphibious wheeled vehicle at Eglin Air Force Base, Fla., and near Khon Kaen, Thailand, to determine the vehicles' capabilities for exiting closed bodies of water. Empirical relations, based on the data collected in this study and in previous studies, are presented to support the conclusions that performance of amphibious tracked and wheeled vehicles (in terms of "go-no go") in the water-land interface can be correlated with soil strength (expressed as average cone index of the 0- to 6-in. soil layer), and that the slope-climbing ability in the water-land interface of the tracked vehicles tested compares favorably with that of the same vehicles operating on land surfaces of similar soil composition and consistency.

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